Stability & Control Challenges for COMSAC: A NASA Langley Perspective

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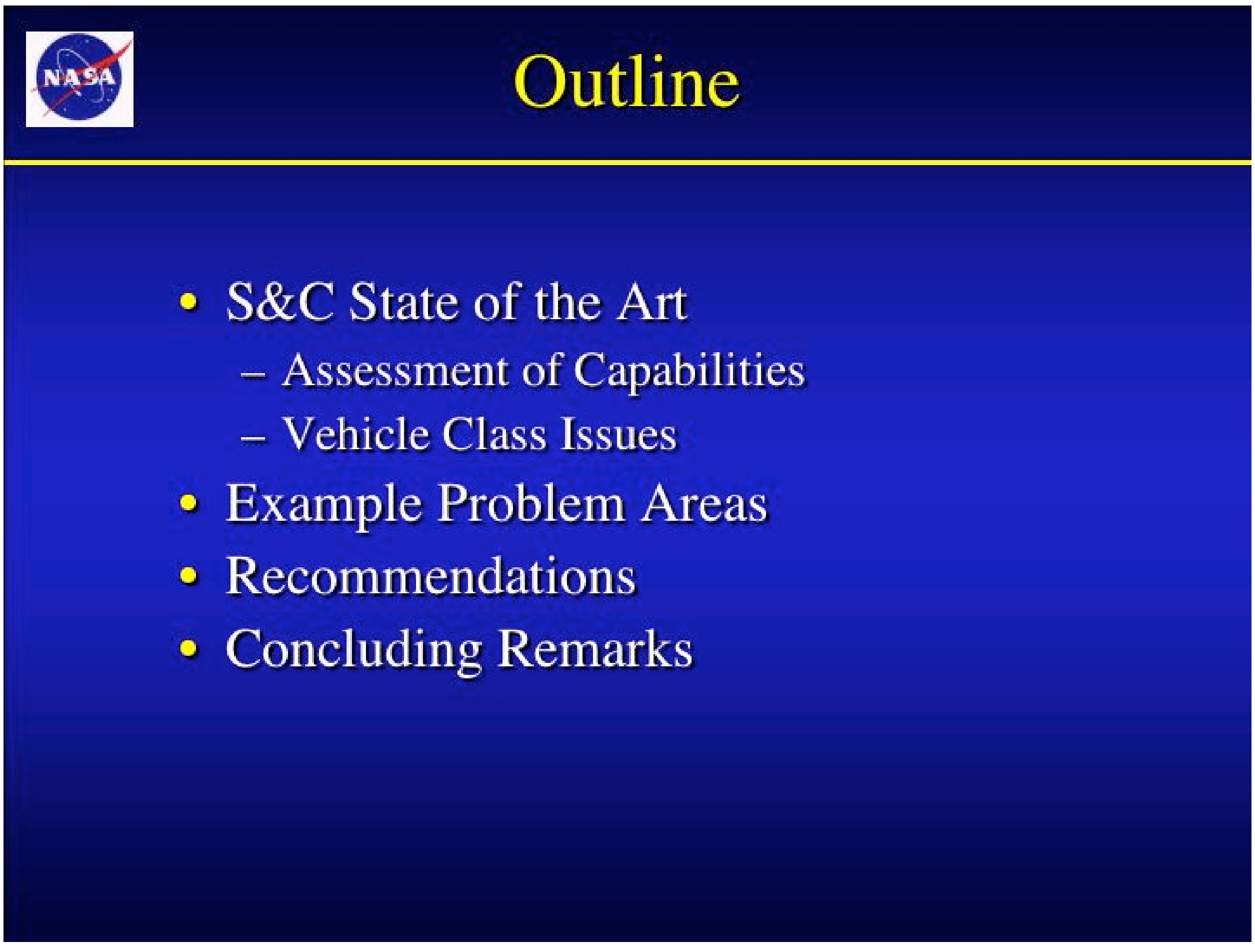
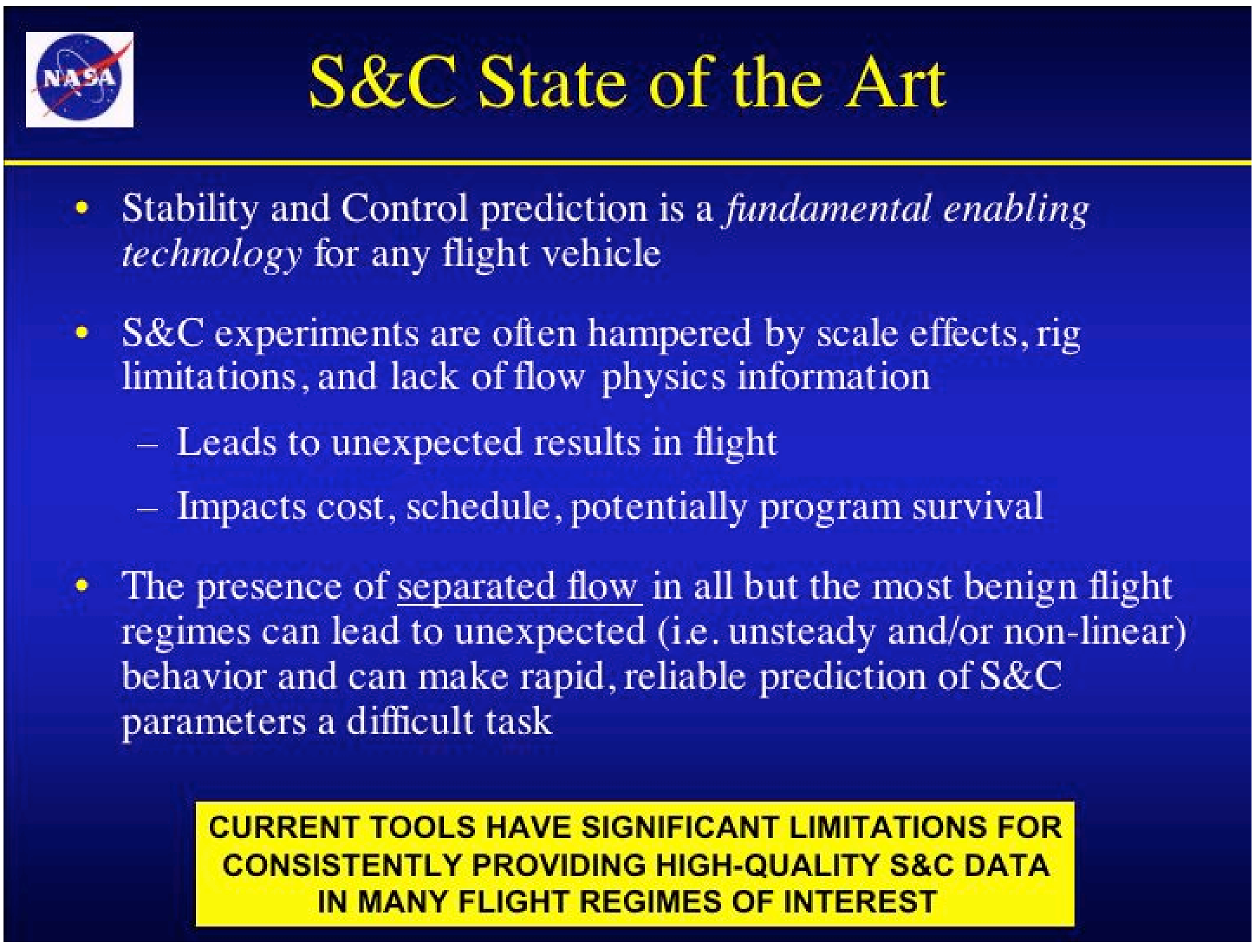
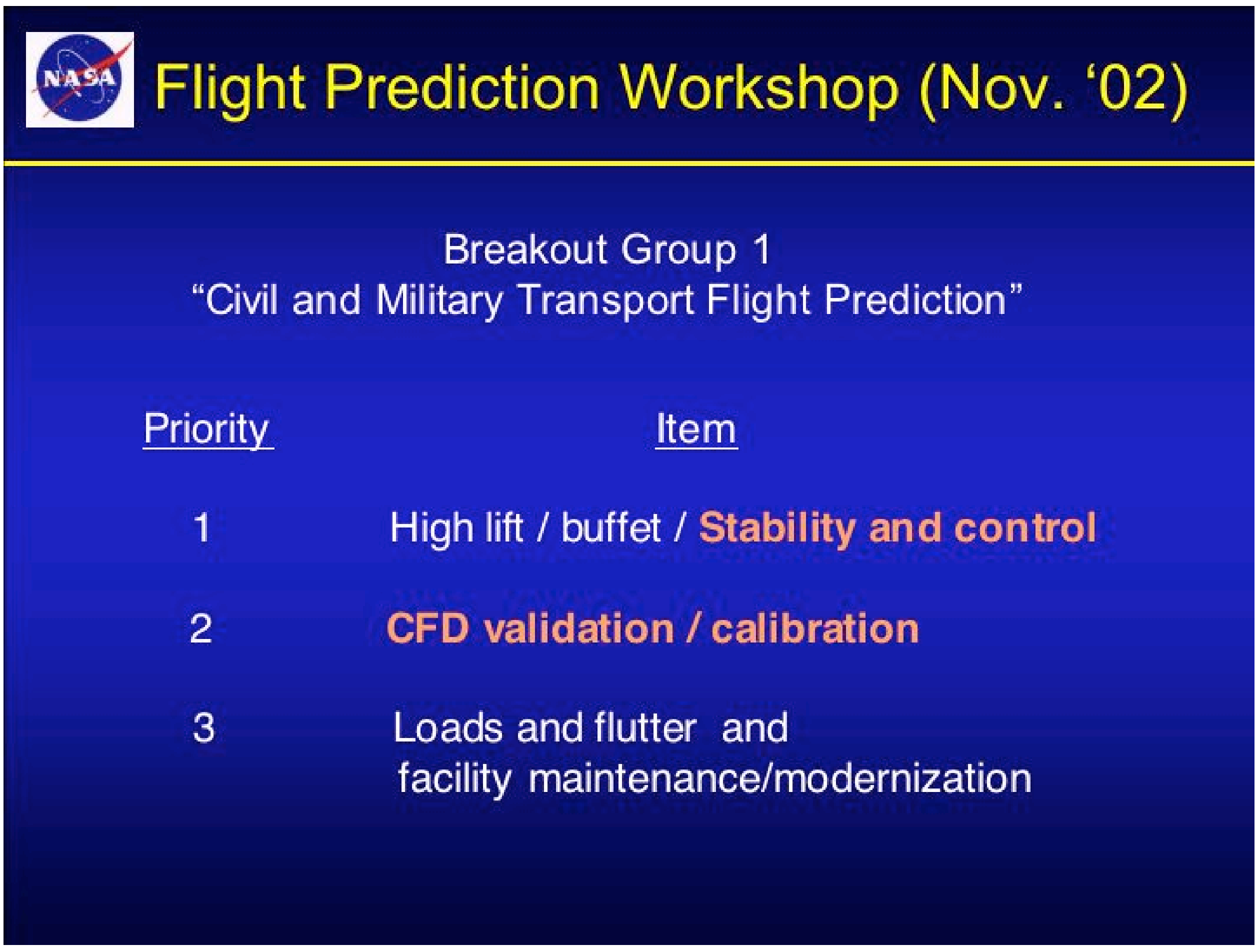
This presentation is designed as a limited-scope "tutorial" and is aimed primarily at the CFDer who has not been exposed to stability and control problems. Examples of some classic S&C problems are used for illustration.



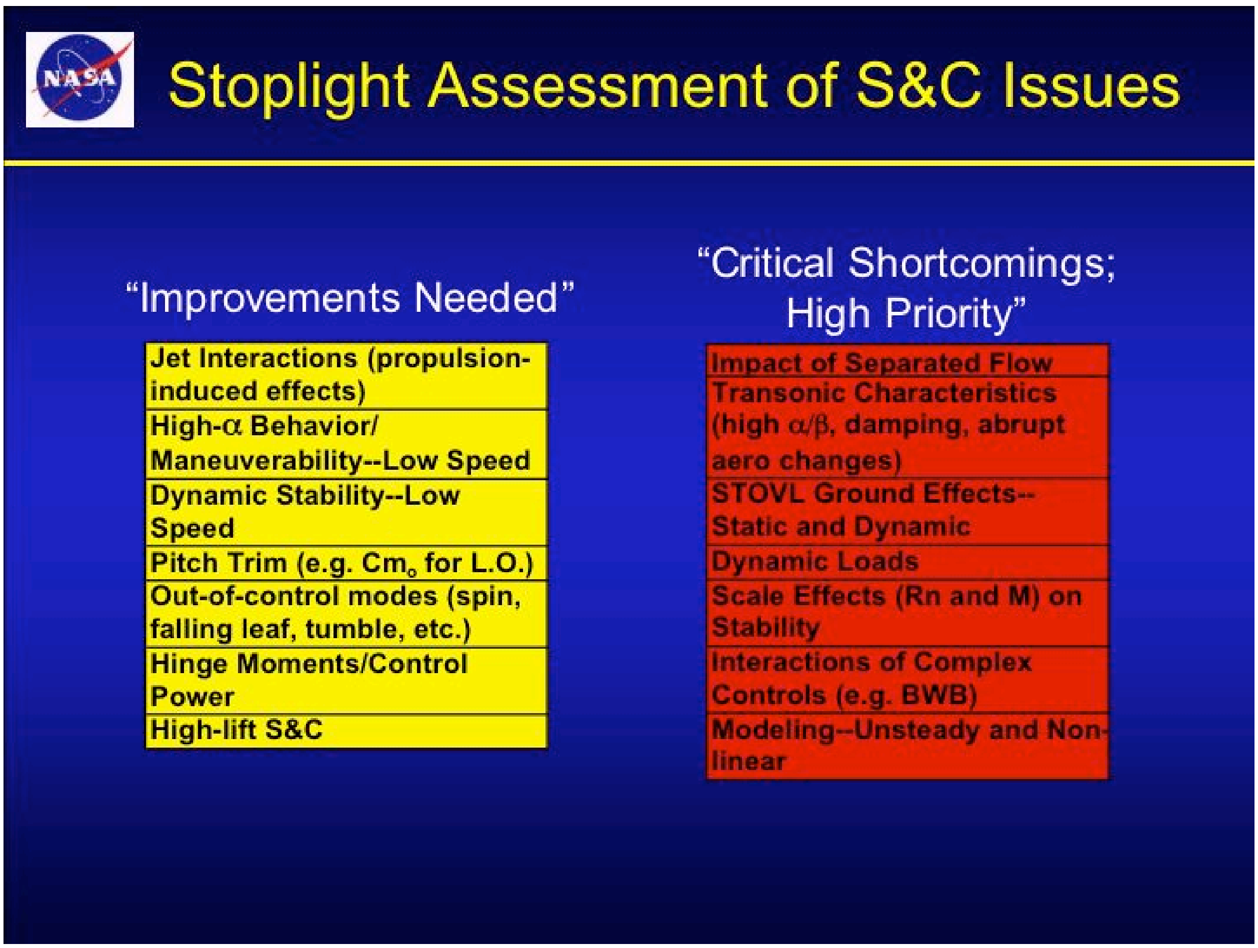
S&C is a fundamental technology for enabling flight, but significant problems with the prediction of S&C characteristics persists, especially where separated flow is involved.
Even after 100 years of flight, experimental methods still have significant limitations.
Experimental and computational tools can and must be complementary.



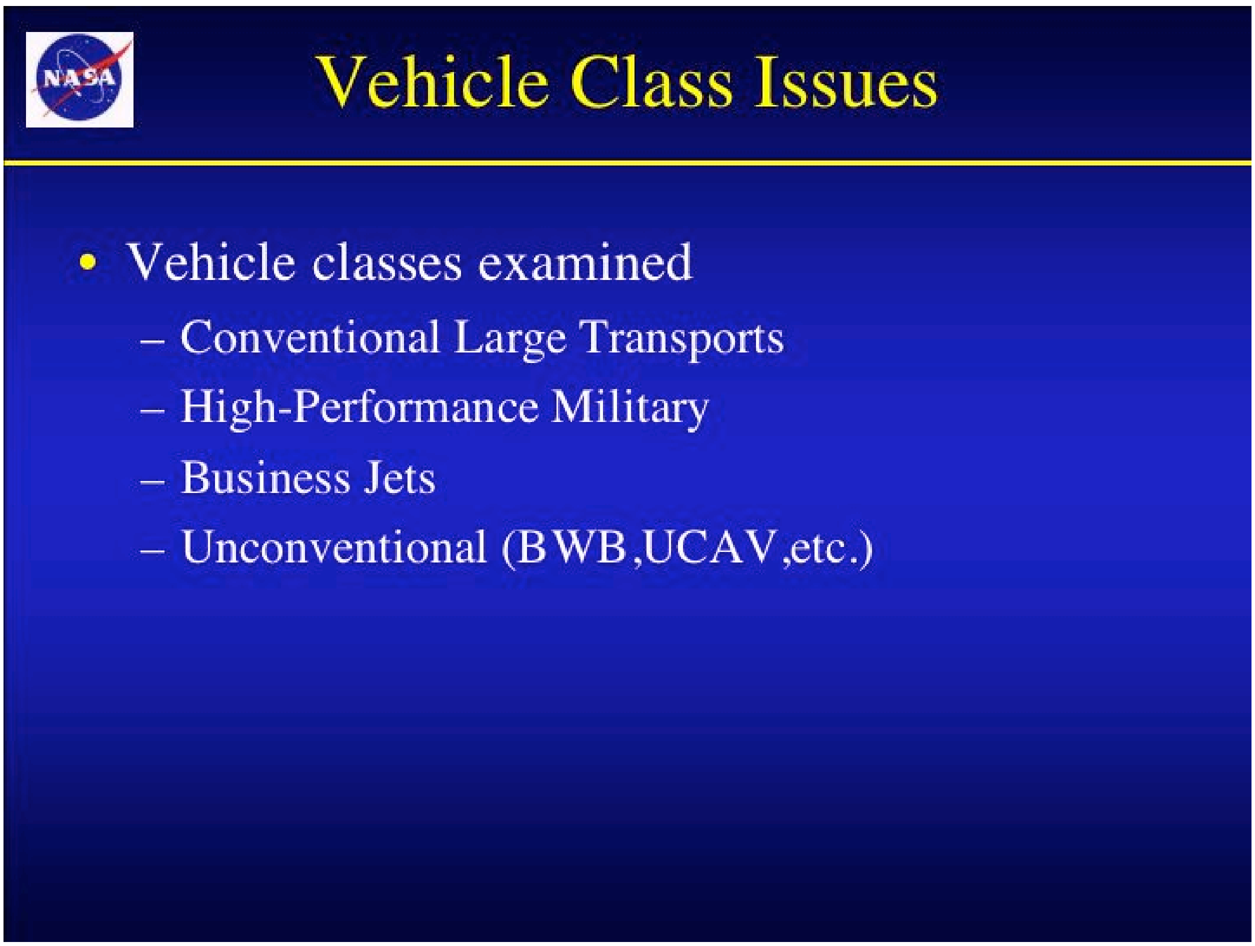
NASA Flight Prediction Workshop (Williamsburg, Virginia, November 2002) brought together experts from government, industry, and academia to discuss problems associated with state-of-the-art flight prediction. Among the concerns highlighted were deficiencies in S&C prediction lack of calibrated CFD tools for aerodynamic prediction in general.



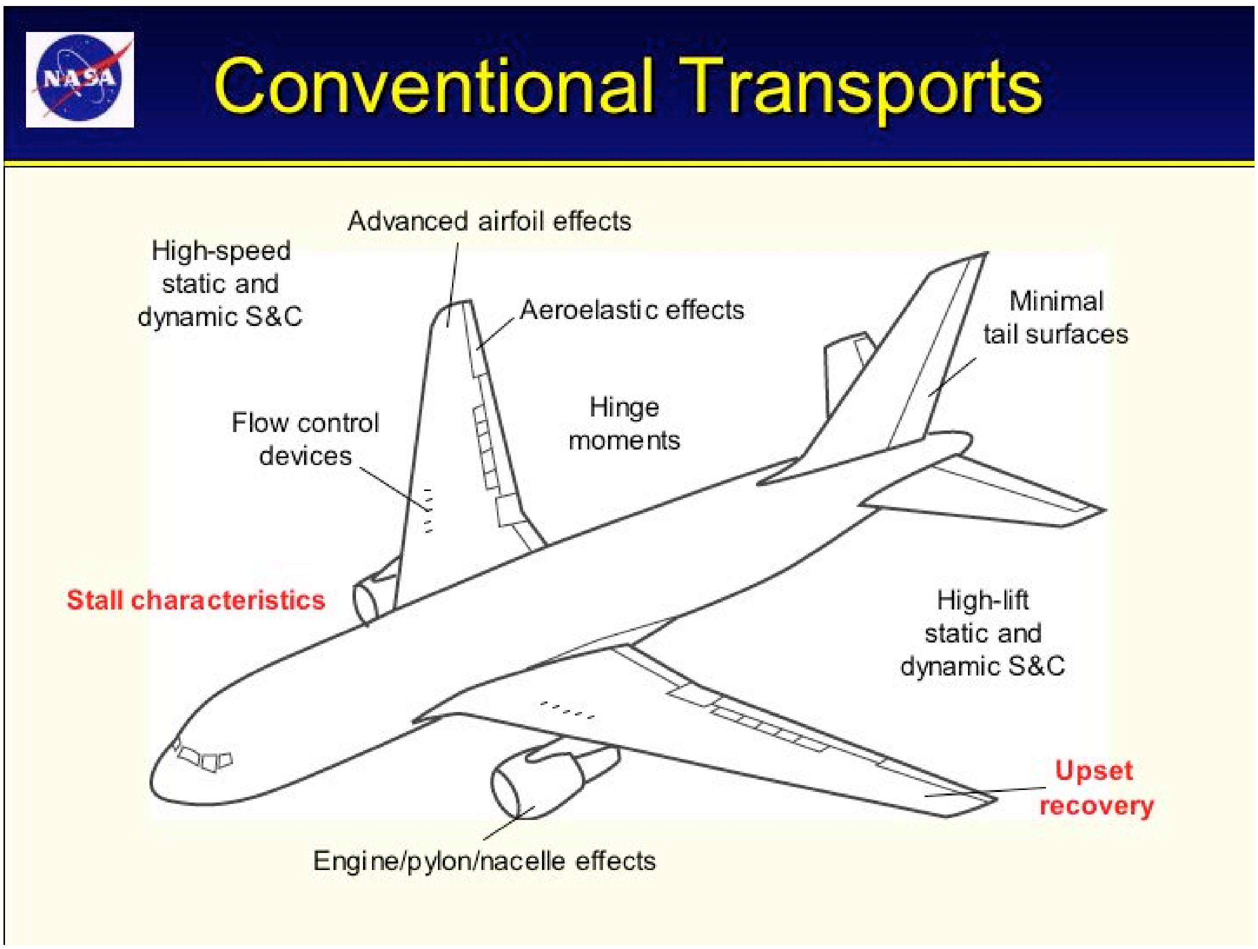
Some problem areas highlighted at the Flight Prediction Workshop, plus a few added by the author.



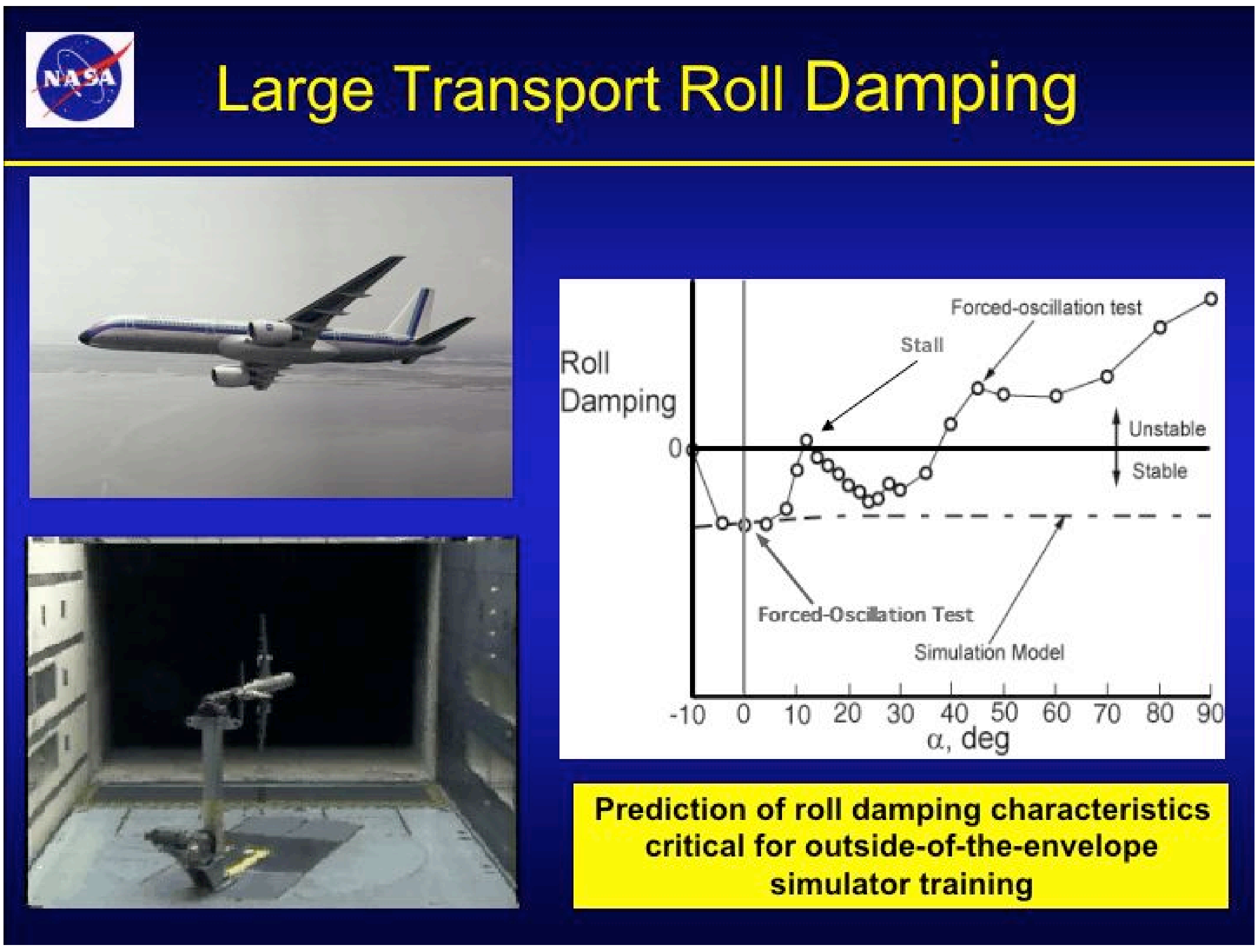
For illustration purposes, problem areas for four “vehicle classes” are examined.



Some issues typically associated with large transports. Items in red are highlighted in the example on the following page.

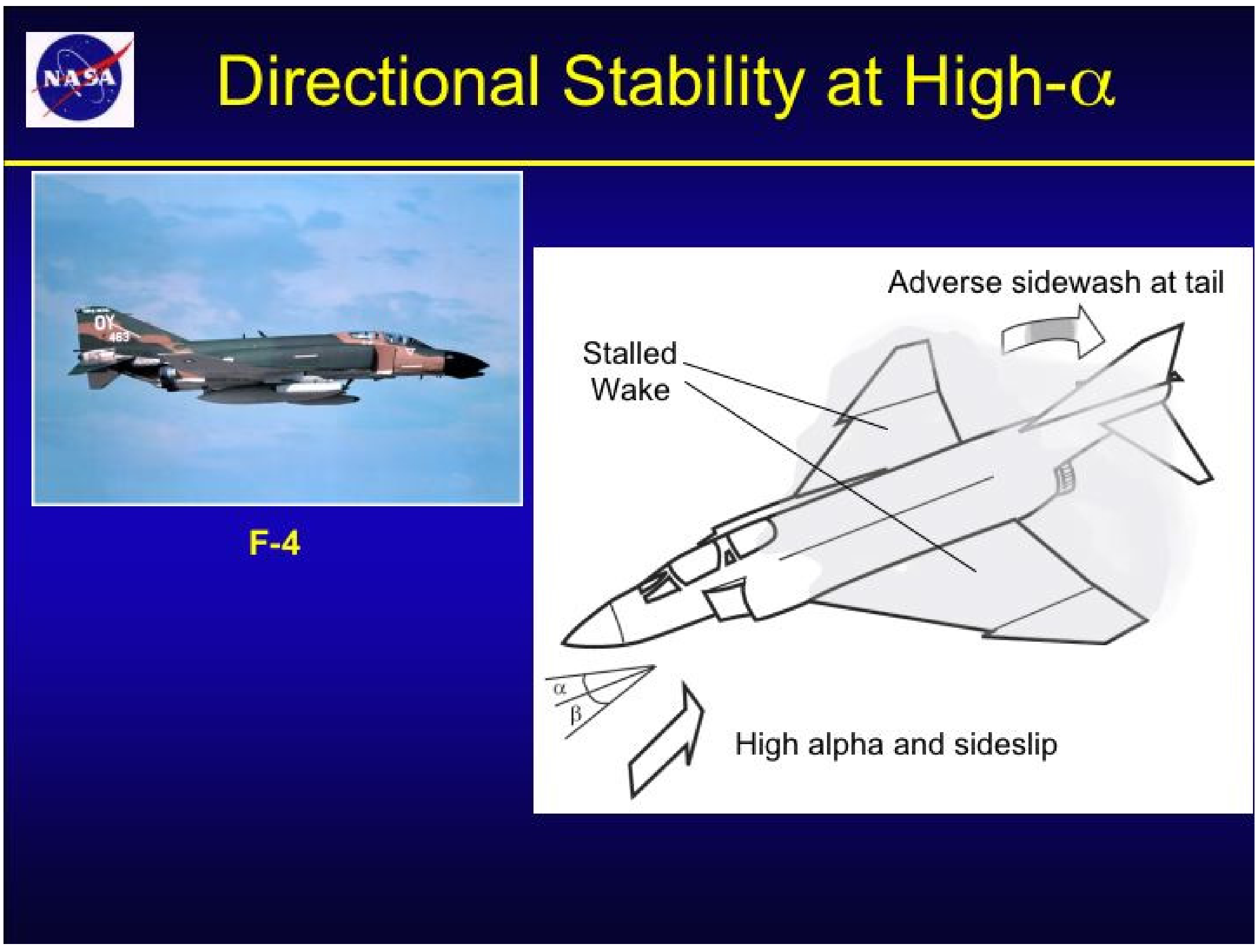


As illustrated by NASA Aviation Safety Program data, roll damping for a large jet transport predicted by the forced-oscillation technique in a wind tunnel is significantly different from that obtained by analytical or handbook methods (e.g. DATCOM), as illustrated by the "Simulation Model" curve. Wind tunnel data indicate that this configuration will have slightly unstable roll damping at stall and will be highly unstable in roll above about 40 degrees angle of attack. Training pilot for stalls and dealing with "out of control" upset conditions may be greatly improved by having better roll damping predictions for simulation.

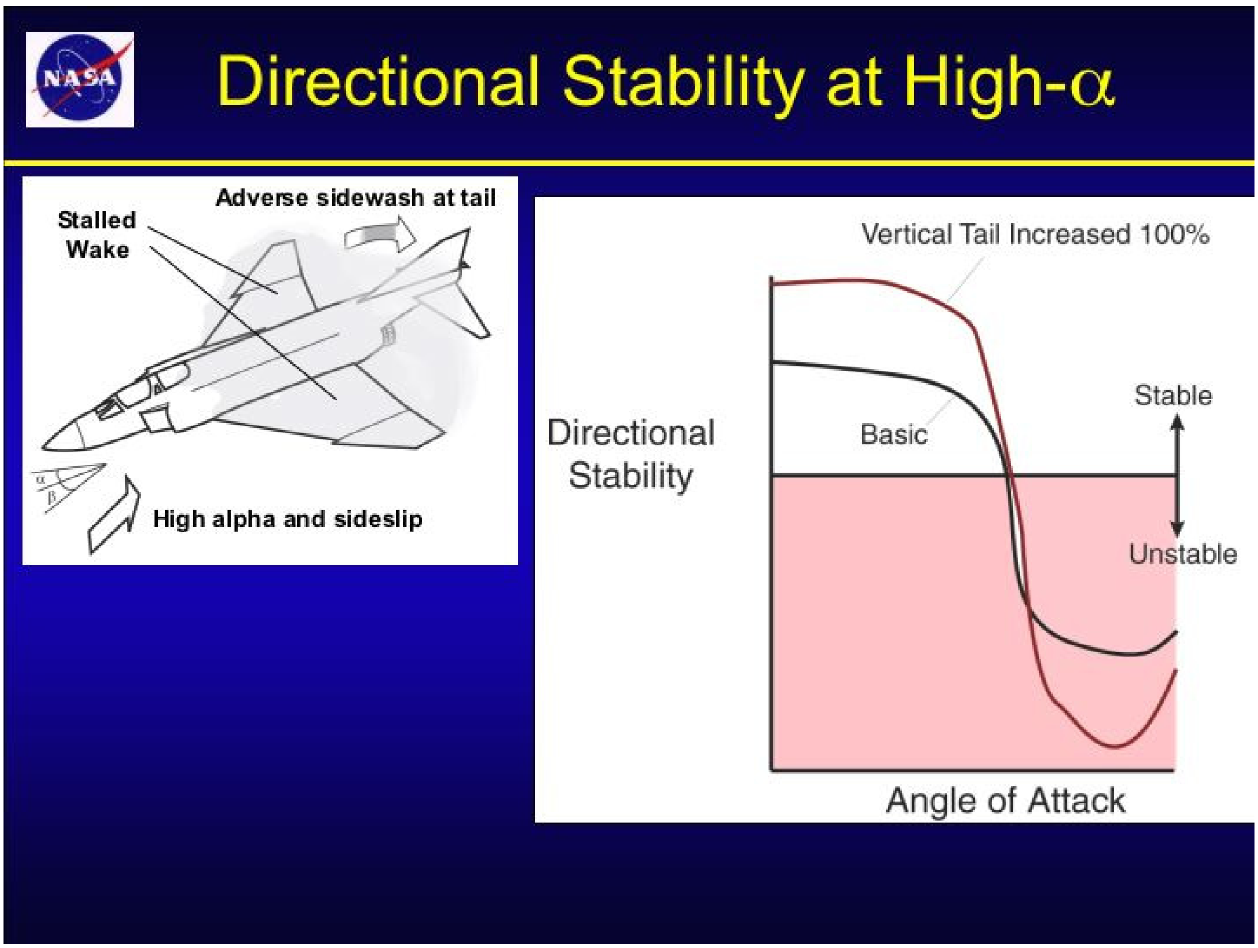


High performance airplanes can have many of the same issues as transports, but there are differences due to the configuration (e.g., sharp leading edge wings, highly swept leading-edge extensions (LEX) or strakes, and close-coupled control surfaces. The fact that these vehicles routinely maneuver at post-stall angles of attack means that flying with separated and vortical flow is the rule, not the exception. Transonic phenomena such as shock-induced wing drop or low-speed wing rock are also not uncommon.

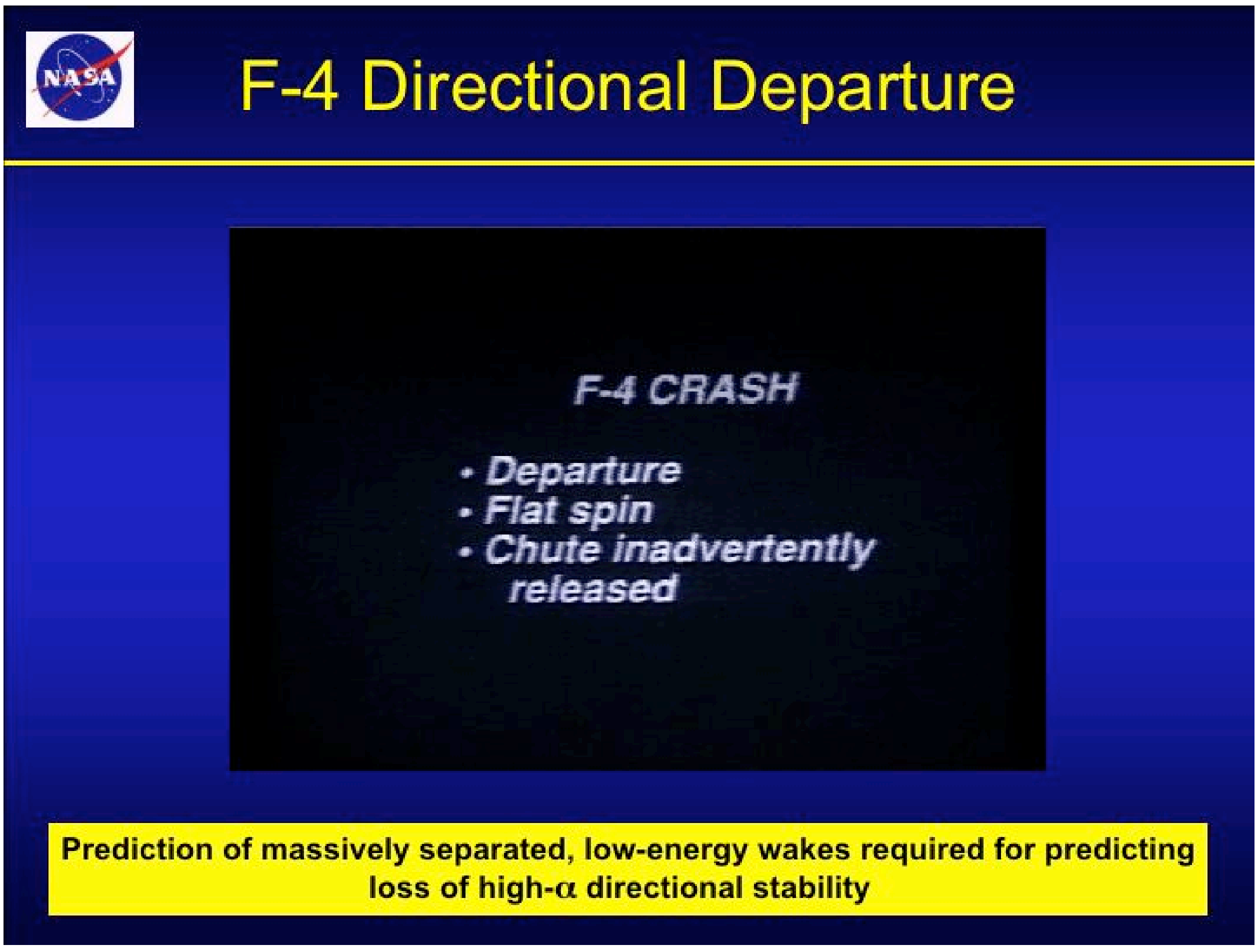
The F-4 was originally designed as a “missile shooter”, not a high-α fighter. During the Vietnam conflict, they were engaged as close-in dogfighters and began suffering significant losses due to spin accidents resulting from loss of directional control at elevated angles of attack. Over 100 Navy and Air Force 100 F-4s were lost before the cause of the problem was identified and resolved by modifications to the leading edge of the wing (slats) to delay stall and improve stall warning. Adverse sidewash at the tail as a contributing factor to loss of directional stability was identified through wind tunnel tests.



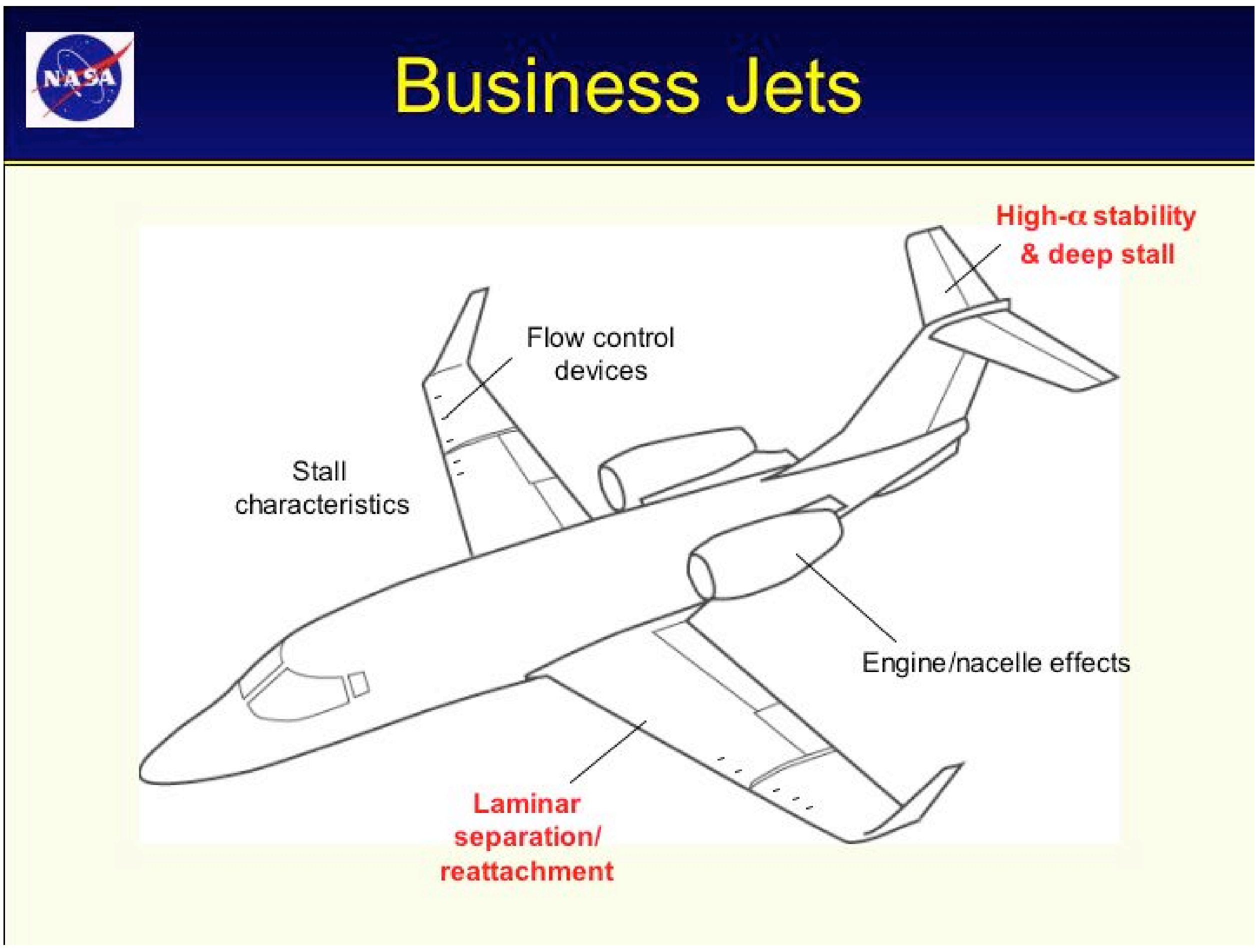
In this case, adding area to the vertical tail to improve directional stability helps for pre-stall angles of attack (i.e., prior to formation of the large wake from the stalled wing), as anticipated, but actually makes the directional instability worse at high angles of attack due to the adverse sidewash at the tail.



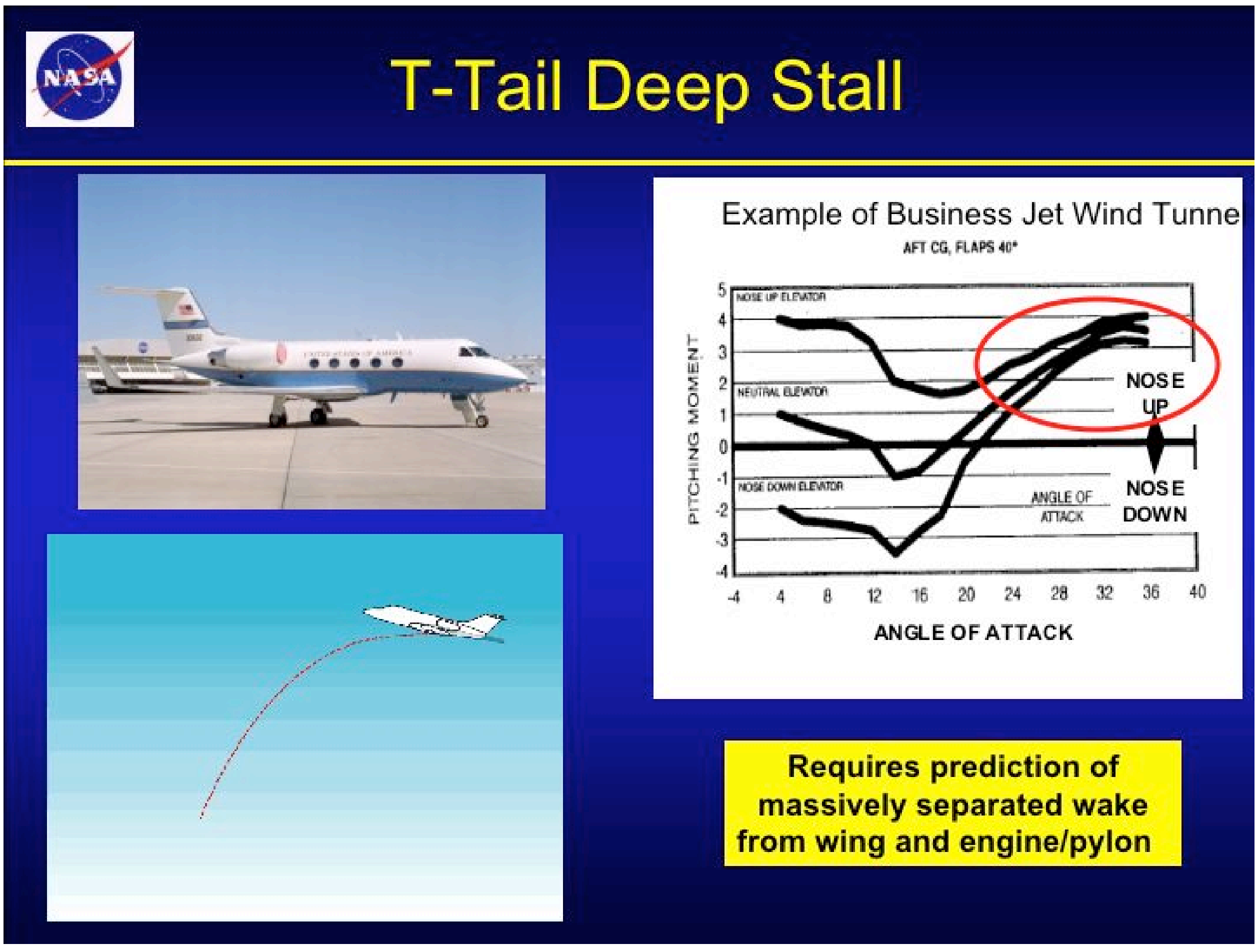
Video of F-4 experiencing directional departure during flight-test wind up turn and entering flat spin illustrates how rapidly the airplane goes from controlled to uncontrolled flight.



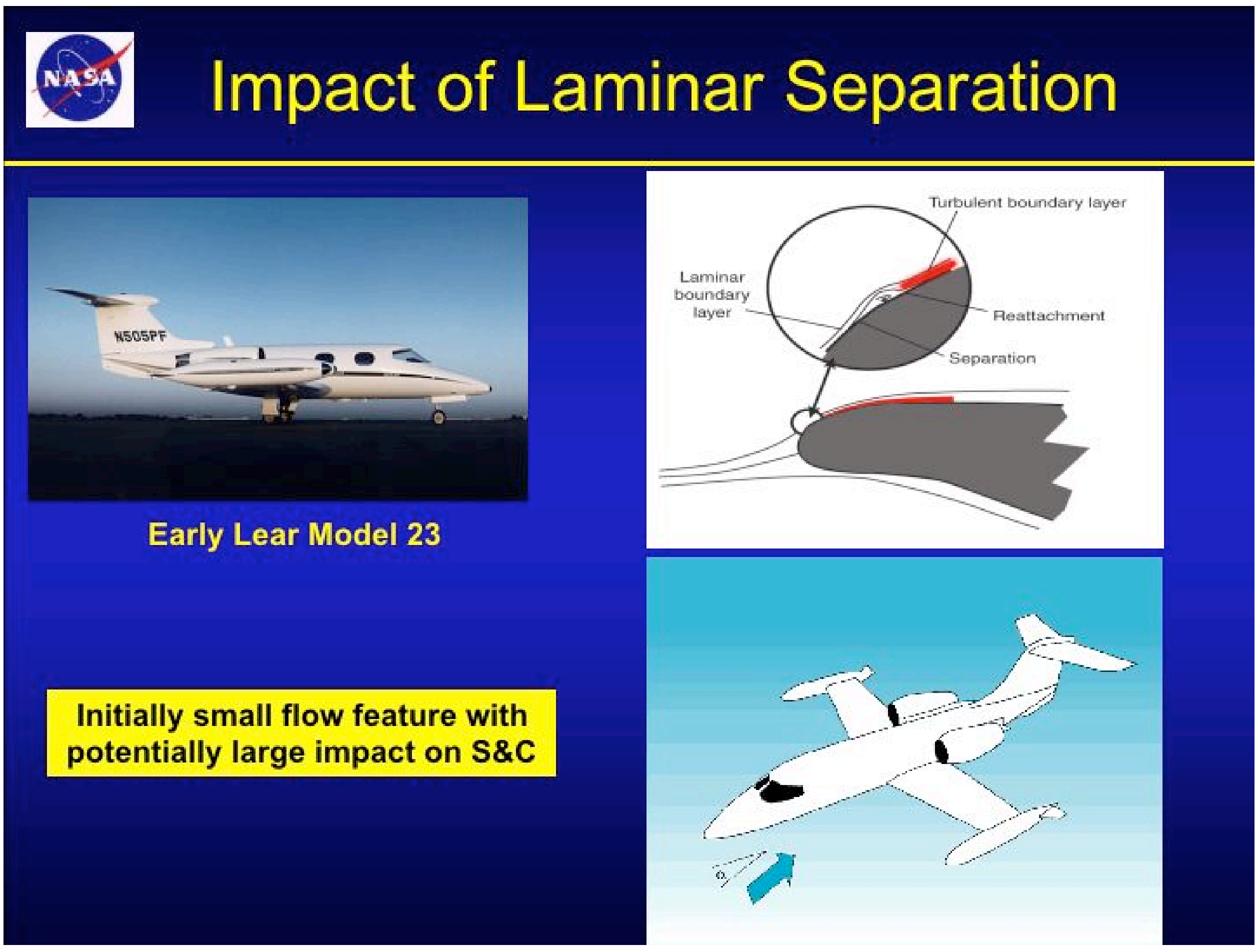
Again, many S&C issues in common with large transports and high-performance fighters, but business jets tend to have T-tails and commonly do not have leading edge devices, potentially leading to issues with deep stall and laminar separation bubbles, respectively.



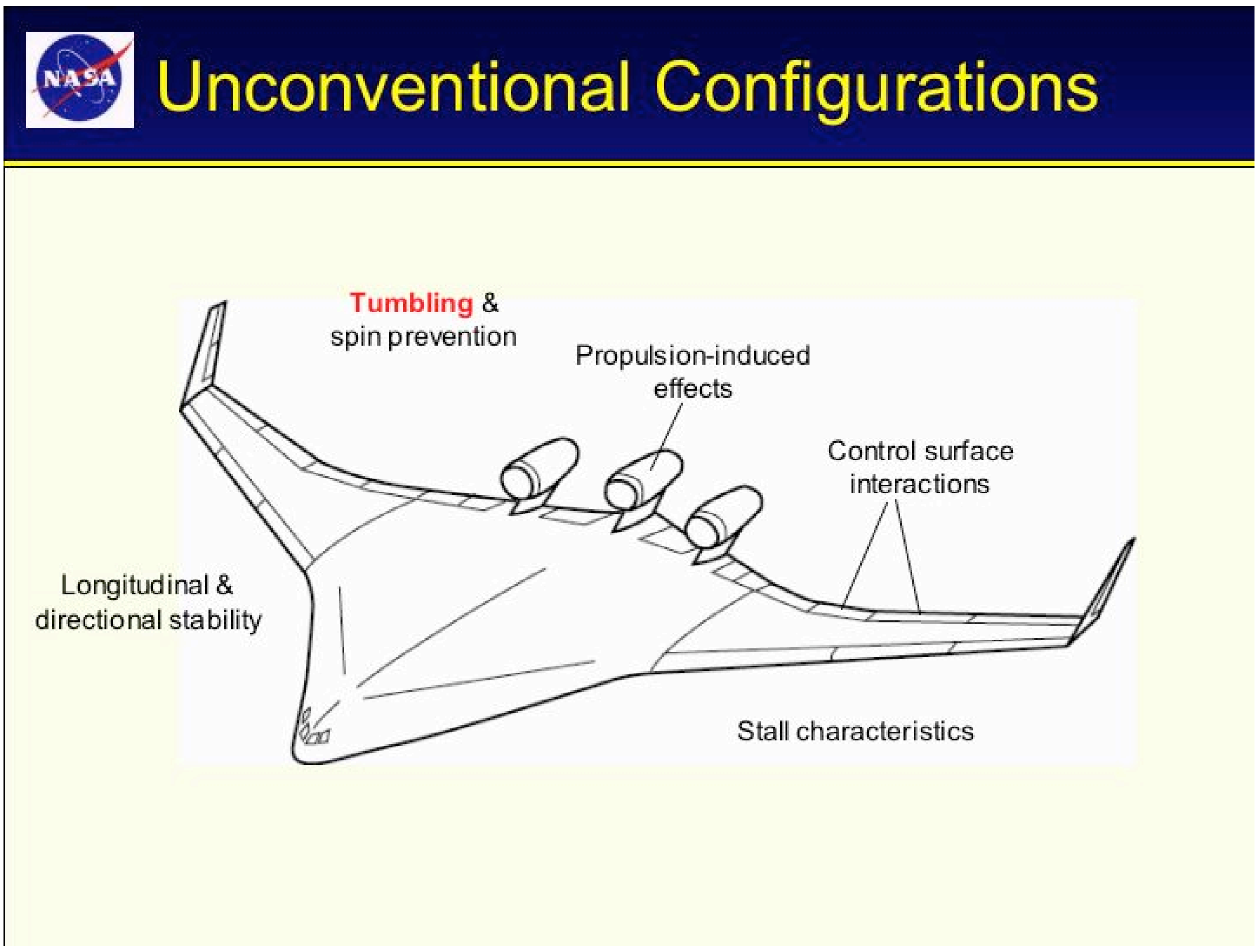
Wind tunnel data (NOT for configuration in photo at left) show that some T-tail airplanes do not have enough nose-down control authority at high angles of attack to recover from a deep stall.



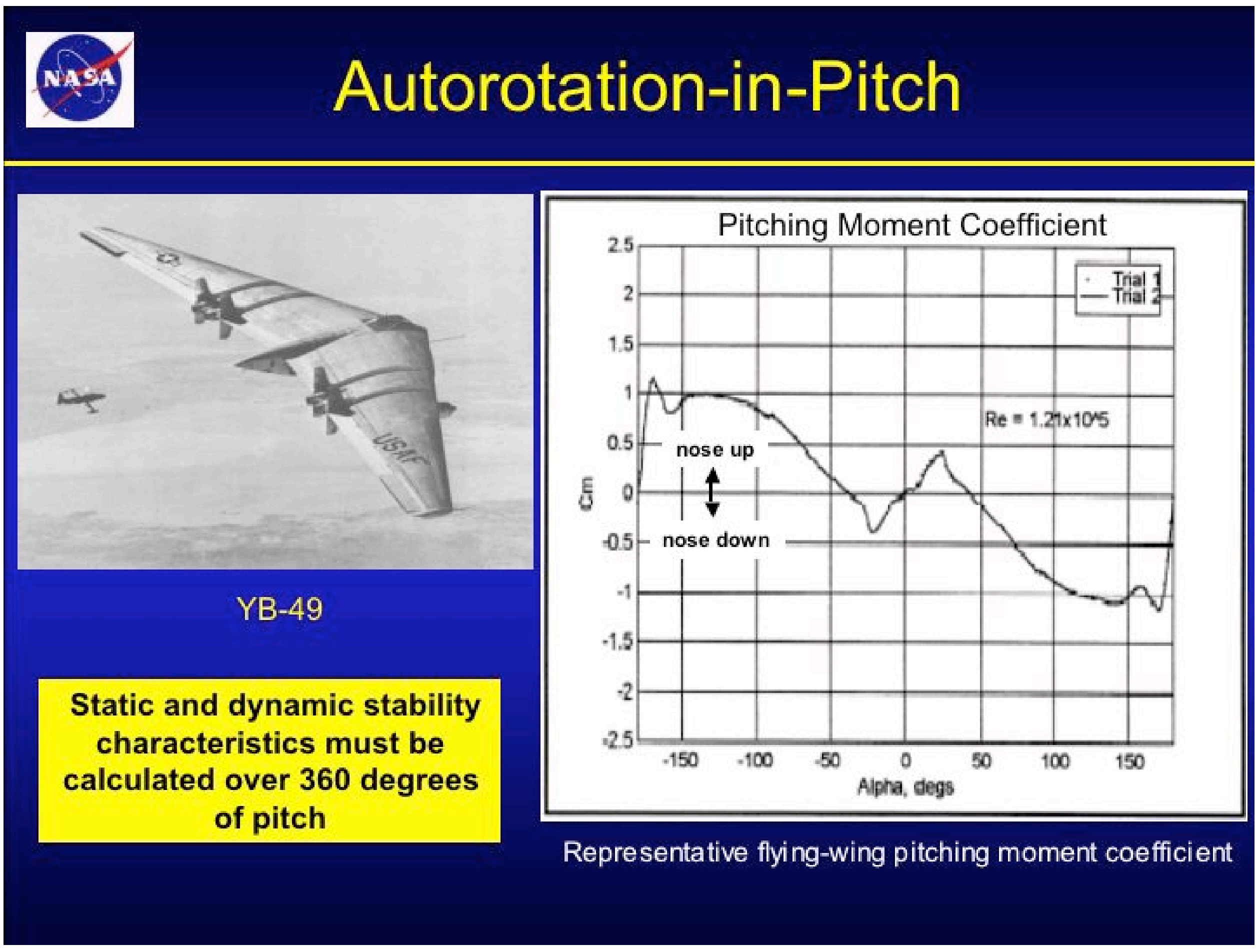
Animation shows laminar separation "bubble" at leading edge at elevated angle of attack (e.g. in landing configuration) progressing to sudden full wing stall on one side after the bubble "lets go" and the entire surface separates abruptly. Large rolling moments are then induced by the asymmetric stall pattern, which is potentially catastrophic if the airplane is at low altitude.



Unconventional configurations such as flying wings are illustrated by the Blended Wing Body (BWB). Flying wings have many distinct S&C characteristics, depending on the geometry, but may include reduced longitudinal and directional stability due to the lack of a tail, highly non-linear control surface interactions if there are multiple control surfaces, and the potential for entering a tumble mode (i.e., autorotation in pitch).



The Northrop YB-49 (and earlier XB-35) were advanced all-wing bombers produced in the late 1940s. Longitudinal stability in general (and tumbling in particular) were identified as potential problems for flying wings early on, and experimental studies were conducted to identify potential problem areas. The plot shows wind tunnel pitching moment data for another flying wing which shows that the vehicle is statically unstable in pitch (I.e., the slope of the curve is positive near zero angle of attack), which could lead to a pitch departure if the dynamic pitch damping is such that rotation is sustained over a complete 360 degree cycle.



Autorotation-in-Pitch

Generic flying wing in LaRC Vertical Spin Tunnel

Recommendations

- Focus on mix of near-term and far-term objectives
  - Combination of component studies and complete configurations
- Collate and assess knowledge of major flow phenomena (stall progression, hysteresis, etc.) to prioritize work
- Critically address the level of code required for specific issues
  - Design, high-fidelity assessments, database, etc.
- Define S&C experimental measurements required for calibration of codes
  - Rn, M, flow physics diagnostics, rigs, testbeds, etc.

S&C community must answer for CFD community:
"How good is good enough?"

Concluding Remarks

- The challenge of predicting aero S&C parameters using CFD is formidable
- The potential payoffs are unprecedented
- Massive amounts of experimental data are available for general guidance
- Very few S&C experiments have been designed for code calibration
- COMSAC must be a close collaboration of the S&C and CFD communities from industry, government, and academia on a national level